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Critical Period for Weed control in Sunflower and Effects of Applications on Weed Species and Diversity

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ABSTRACT

This study was carried out under field conditions in Adana, Turkey in 2018 and 2019 to determine the critical period for weed control in sunflower depending on the daily growth temperature (GDD) and weed species. A log-logistic model with four parameters was used to determine the relationship between relative crop yield and both increased weed intervention time and length of weed-free periods. In addition, dominant weeds and weed densities were determined in the experimental area. Data obtained from different periods of weed intervention were compared with data obtained from seasonal weed-free plots. During the sunflower growing season, 37.4% – 41.04% yield loss was determined in sunflower due to weed competition. For 5% acceptable yield loss in the first year, the critical period in weed control was determined as 243-1181 GDD; this is 24-86 days after the crop emergence (DAE) . It was found between 269 and 1409 GDD (16-72 DAE) in the second year. In sunflower, it was determined that the removal of weeds from the plot in the weed-free period started within 2-3 weeks from the emergence and continued for 10-12 weeks. These findings may help sunflower growers to plan and implement cost-effective and appropriate weed control programs.

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Ayçiçeğinde Yabancı Ot Kontrolünde Kritik Periyot ve Uygulamaların Yabancı Ot Türleri ve Çeşitliliğine Etkileri

ÖZET

Bu çalışma, ayçiçeğinde günlük gelişme sıcaklığı (GDD) ve yabancı ot türlerine bağlı olarak ayçiçeğinde yabancı ot kontrolü için kritik periyodu belirlemek amacıyla 2018 ve 2019 yıllarında Türkiye'nin Adana ilinde tarla koşullarında yürütülmüştür. Dört parametreli bir log-lojistik model, bağıl mahsul verimi ile hem artan yabancı ot müdahale süresini hem de yabancı otsuz dönemlerin uzunluğu arasındaki ilişkiyi ortaya koymak için kullanıldı. Ayrıca deneme alanında baskın yabancı otlar ve yabancı ot yoğunlukları da belirlenmiştir. Yabancı ot müdahalesinin farklı dönemlerinden elde edilen veriler, mevsimlik yabancı otsuz parsellerden elde edilen verilerle karşılaştırılmıştır. Ayçiçeği yetişme mevsimi boyunca yabancı ot rekabetinden dolayı ayçiçeğinde %37,4 – %41,04 verim kaybı belirlenmiştir. ilk yıl %5 kabul edilebilir verim kaybı için yabancı ot mücadelesinde kritik periyot süresi 243-1181 GDD olarak belirlenmiştir ki bu, ayçiçeğinin çıkışından sonraki 24-86. günler arasına (DAE) denk gelmektedir. İkinci yılda ise bu süre 269 ve 1409 GDD (16-72 DAE) arasında bulunmuştur. Ayçiçeğinde, yabancı otsuz dönemde yabancı otların parselden uzaklaştırılması çıkıştan itibaren 2-3 hafta içinde başladığı ve 10-12 hafta boyunca devam ettiği belirlenmiştir. Bu bulgular, ayçiçeği yetiştiricilerinin düşük maliyetli ve uygun yabancı ot kontrol programlarını planlamasına ve uygulamasına yardımcı olabilecektir.

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INTRODUCTION

Sunflower, which is an important oil plant, comes after palm, soybean and canola in the world vegetable oil production and meets a significant part of the oil need in the world. Sunflower is grown in sowing area of 26.668.100 ha and annual production is approximately 52 million tons in the world (FAO 2018). Sunflower, one of the most important oil plants in the world and in Turkey, is an oil plant with the highest cultivation area and production amount in Turkey such that 46% of the required vegetable oil production is provided from sunflowers (TUIK 2018). Today, the most effective way to solve the nutritional problem that occurs with the agricultural production areas reaching the last limit is to find the ways to get the highest yield per unit area via using agricultural inputs in the most appropriate way.

Weeds are considered one of the main factors that reduce the quantity and quality of agricultural production (Uludag et al., 2018). Sunflower has tall, broad leaves and strong root structure. It is more competitive with weeds than other cultivated plants. However, since they do not develop as fast as weeds, they compete with weeds in the early period (1-1.5 months after sowing) and cannot show a homogeneous development in the field. This period is considered the critical period for sunflower. Weeds that germinate in the same month as sunflower develop rapidly and put the sunflower under pressure (Özer et al., 2003). Yield losses due to weeds in sunflower may vary between 26-52%, although it is has been reported that this losses may increase up to 90% (Wanjari et al., 2000; Gholipour et al., 2010; Asghari et al., 2011; Serafin et al., 2014; Mukhtar et al., 2018). Identifying weeds that cause problems in sunflower fields helps in their control. In agricultural systems crop cultivation applications determine the diversity of weed species (Uremis et al., 2009a). Biodiversity in agricultural land is gradually decreasing due to limited crop rotations, use of intensive agricultural inputs and pesticide applications (Chaudhary et al. 2015). Weeds are considered one of the main reasons that reduce the quantity and quality of agricultural production (Uludag et al. 2018). Weeds cause problems in sunflower fields and identifying weed communities that they compose with each other help in their control. As a matter of fact, the presence of any member of the weeds forming a community in the field indicates the presence of others and management programs are organized according to this community (Zengin 1999).

CPWC (the critical period for weed control) studies are an important part in the development of integrated weed management strategies (Swanton and Weise, 1991) and generally allow determination of weed control strategies (Weaver and Tan, 1987). Weed control methods and application costs are effective in the emergence of the most appropriate time. (Van Acker et al. 1993). In order to implement a successful integrated management program, it is necessary to know the economic thresholds of weeds, plant formation rates, competitive ability, germination and development biology as well as critical period (Uludag et al., 2018; Uremis and Uludag, 2020).

CPWC makes an important contribution to the determining the time to weed to reduce yield or quality losses from weeds in the crops (Uludag et al., 2012). CPWC allows the measurement of the negative effects of weeds on crop growth and yields (Chauhan and Johnson, 2011). There are two different intervals: the beginning and the end of the CPWC in which weed competition is examined by recording early and late period weed density and biomass (Knezevic et al., 2002). While weed competition in the early period is evaluated by removing weeds until harvest and allowing them to emerge and grow with the product at certain periods, in the late period weed competition is the presence of weeds during the growing season of the crops and the retention of weeds at certain periods (Tursun et al., 2007). CPWC is influenced by a variety of factors, including: crop species and variety; weed species; and environmental conditions (Uremis et al., 2009b; Tursun et al., 2015, 2016a, b; Abaci and Uremis, 2016). Changes in weed flora and environmental conditions limit the generalization of CPWC results (Knezevic et al., 2002).Some studies show that CPWC varies depending on the period and region in which the crop is grown (Tursun et al., 2016a and 2016b). These changes vary according to environmental conditions and the species and density of weeds (Uludağ et al., 2012).Therefore, in this study, it was aimed to (i) determine the crop losses in sunflower according to weed removal time (ii) determine the critical period for weed control (CPWC) in sunflower depending on the growing degree days (GDD) (iii) determine the effect of weeds removal times on weed species.

MATERIAL and METHODS

This study was conducted in Ceyhan / Adana (37.10

^{0}N, 35.41 ^{0}E) in 2018 and 2019, in order to determine the competition between weeds and sunflower and to reveal the species richness according to the weed removal time and period that is the basis for weed control. The soil structure of the experimental area was loamy clay (Table 1). The oil sunflower cultivar 'LG 5485' seeds were sown on 10 March 2018 and 02 May 2019 with 70 cm spacing between rows and 35 cm plants on a row. Trial plots were irrigated when needed. The studies were carried out in 2018-2019 and were arranged in three replications according to the randomized blocks experimental design. The plot sizes are set to 2.8 m x 3 m (8.4 m^2). In the experiment, 0.5 m distance between parcels and 1 m distance between blocks was left. The experiment conducted on a total of 42 plots. Two types of weed removal treatments were implemented from the start of sunflower emergence.

In order to evaluate the onset of the critical period with weed removal, plots were left weedy for 15, 30, 45, 60, 75 and 90 days after crop emergence (DAE). To determine the end of critical period, plots were kept weed-free for 15, 30, 45, 60, 75 and 90 DAE by periodic hand hoeing. The season long weedy and weed-free control treatments were also established in the study. Each experimental plot was consisted of four rows of sunflower plants and two outer rows of each plot were used as buffer rows and two central rows were used for assessments. The weed-free control plots were kept weed-free for the entire growing season by hand hoeing by removing weeds as soon as the appeared.

Table 1. Soil structure of the experimental field (0-30 cm soil depth)

Çizelge 1. Deneme alanının toprak yapısı (0-30 cm toprak derinliği)

Soil characteristics	Values
Saturation (%)	65.78
pH (1 : 2.5)	7.83
P_2O_5 (mg kg^{-1})	3.37
Organic matter (%)	2.15
K_2O (mg kg^{-1})	126.00
Total soluble salt (%)	0.025
Iron-Fe (mg kg^{-1})	5.20
Manganese-Mn (mg kg^{-1})	0.45
Lime-$CaCO_3$ (mg kg^{-1})	6960.00
Magnesium (mg kg^{-1})	1333.20

Data Collection

Growing degree days (GDD) shows the daily temperature sums for a plant to reach maturity. GDDs were calculated using air temperatures according to Gilmore and Rogers (1958). Sunflower emergence dates were used as starting point for the sum of the GDD.

$$GGD = [(T_{max} + T_{min}) / 2] - T_b \qquad \text{(Equation 1)}$$

T*min* and T*max* were taken as the daily minimum and maximum temperature, respectively. Basic temperature (Tb) for sunflower germination is 6.7 °C (Khalifa et al. 2000). Accordingly, weed removal times were determined based on GDD calculations.

Monthly average temperature and precipitation data during the sunflower growing seasons were obtained from the Meteorology Service, Adana, Turkey (Table 2). Species composition and weed density were evalueted before the completion of each treatment for plots weedy in the beginning and in harvest time for plots left weed after certain times by classifying and counting weeds in 3 fixed points of 1 m^2. Above-ground dry biomass was specified by cutting weeds at the soil surface inside the quadrants and drying at 105 °C for 24 hours. In both years, measurements were made when sunflowers reached harvest maturity. Harvest dates for 2 years in all plots were determined as 10 July 2018 and 15 August 2019 in all plots. Sunflower plants were harvested by hand from the middle two rows of each plot and necessary measurements were made

Table 2.Total monthly precipitation and average temperature for sunflower growing season

Çizelge 2. Ayçiçeği gelişme mevsimi boyunca toplam aylık yağış ve ortalama sıcaklık değerleri

Months	Rainfall (mm)		Average temperature (^{0}C)	
	2018	2019	2018	2019
March	1.26	0.00	15.35	-
April	1.19	0.00	18.73	-
May	2.85	0.01	22.85	23.56
June	1.59	1.27	25.37	26.23
July	0.48	1.04	28.32	27.45
August	0.00	0.00	-	28.70

Statistical analyses

The sunflower yield after each application was compared with the weed-free control application to obtain relative yields (percent weed free). R software (R version 3.5.3, R Development Core Team, 2018) including the drc (dose-response curves) statistical plug-in package was used for statistical analysis (Knezevic et al., 2007; Knezevic and Datta, 2015).

Statistical analysis was performed separately for each year due to variations in GDD. Analysis of variance (ANOVA) was applied to the data to determine the importance (P <0.05) of treatments, repetitions, and their interactions. Then, further analysis was performed for the factors significant in the F-test (P ≤ 0.05). A four-parameter log-logistic model was used to analyze data on relative yield. The D term remained constant at 100 (Knezevic et al. 2007).

$$Y = C + \frac{(D-C)}{(1+Exp\left[B(LogX - LogE)\right]} \qquad \text{(Equation 2)}$$

D: upper limit,

Y: % sunflower yield
C: lower limit
X: GDD

E: GDD indicating a 50% response between the upper and lower limit (also known as inflection point, I50)

B: slope of the line at the inflection point (also known as a rate of change)

The use of GDD is the best variable for regression models according to the categorical variable, as it provides a precise and continuous scale on the x-axis. AYL2.5 (2.5% acceptable yield loss), AYL5 (5% acceptable yield loss) and AYL10 (10% acceptable yield loss) were provided from the calculated curves to determine the target range in measuring the effect of increasing time on weed presence and weed-free treatments on crop yield. The 2.5, 5 and 10% yield decreases periods are given as GDD for determining the effects of the duration of weed interference, and the estimated GDD corresponding to the 90, 95 and 97.5% relative yield was calculated from Equation 2 for each year's sunflower yield and WAE. According to the yield losses, in this study, yield losses above 5% yield loss were considered to be unacceptable (Knezevic et al., 2007).

In addition, Shannon-Wiener (H) index were used and Simpson dominance index (Sd) were used in the dominance of weeds in determining the diversity of weed species in each weed removal and season-long weeds in the experimental area. The Shannon-Wiener (H) index was used to determine the diversity of weed species in each weed removal and season-long weedy plots in the experimental area and Simpson dominance index (Sd) was used for dominance of weeds.

Shannon-Wiener diversity index (H)

$H = -\sum p_i \ln (p_i)$

Where,

pi: ratio of i'th type to others

ln: shows the natural logarithm base (Magurran 2004).

Simpson dominance index (Sd)

$Sd = \sum n_i(n_i-1)/N(N-1)$

where,

i: Number of species

ni: Number of weeds belonging to a species

N: It shows the total number of individuals of the species in an application (Magurran 2004).

RESULTS and DISCUSSION

Weed Richness, Abundance, Diversity and Biomass

The experiments were carried out in a field naturally contaminated with weeds in 2 years. Important weeds found in 2018 were *Chenopodium album* L., *Convolvulus arvensis* L., *Cyperus rotundus* L., *Heliotropium europaeum* L., *Chenopodium vulvaria* L., *Chrozophora tinctoria* (L.) Rafin., *Euphorbia prostrate* Aiton, *Prosopis farcta* (Banks and Sol.) J.F.Macbr., *Fumaria officinalis* L., *Polygonum aviculare* L. and *Cynodon dactylon* (L.) Pers.; and In 2019, *C. album*, *C. arvensis*, *C. tinctoria*, *C. rotundus*, *C. vulvaria*, *C. tinctoria*, *P. farcta*, *Cucumis melo* var. *Agrestis* Naud.,*Echinochloa colonum* (L.) Link., *E. crus-galli*, *H. europaeum*, *Physalis angulata* L. and *Sorghum halepense* (L.) Pers. (Table 3).

Table 3. Dominant weeds and their average densities in control plots in 2018 and 2019.
Çizelge 3. 2018 ve 2019 yıllarında control parsellerinde görülen baskın yabancıotlar ve ortalama yoğunlukları.

Common name	Scientific name	2018		2019	
		Weeds per m^{-2}	%	Weeds per m^{-2}	%
Common lambsquarters	*Chenopodium album* L.	3.33	11.50	1.02	7.70
Stinking goosefoot	*Chenopodium vulvaria* L.	3.30	11.39	--	--
Turnsoler weed	*Chrozophora tinctoria* (L.) Rafin.	0.51	1.75	0.93	6.99
Field bindweed	*Convolvulus arvensis* L.	3.90	13.47	0.18	1.34
Common cucumber	*Cucumis melo* var. *agrestis* Naud.	--	--	0.47	3.57
Bermuda grass	*Cynodon dactylon* (L.) Pers.	0.06	0.22	--	--
Purple nutsedge	*Cyperus rotundus* L.	14.28	49.32	3.66	27.65
Jungle-rice	*Echinochloa colonum* (L.) Link	--	--	0.27	2.06
Barnyard grass	*Echinochloa crus-galli* (L.) P.Beauv.	--	--	0.19	1.43
Prostrate spurge	*Euphorbia prostrate* Aiton	0.19	0.65	0.40	3.04
Common fumitory	*Fumaria officinalis* L.	0.28	0.98	--	--
European heliotrope	*Heliotropium europaeum* L.	1.24	4.27	1.21	9.14
Cutleafgroundcherry	*Physalis angulata* L.	--	--	0.08	0.61
Prostrate knotweed	*Polygonum aviculare* L.	0.03	0.11	--	--
Syrian mesquite	*Prosopis farcta* (Banks and Sol.) J.F.Macbr.	0.95	3.28	4.58	34.56
Broadleaf dock	*Rumex obtusifolius* L.	0.89	3.06	--	--
Johnsongrass	*Sorghum halepense* (L.) Pers.	--	--	0.25	1.88
Total		28.96	100.00	13.25	100.00

In 2018 and 2019; *C. album, C. arvensis, C. rotundus, H. europaeum, C. vulvaria, C. tinctoria,* and *P. farcta* were common weeds. In addition, these determined weeds are similar to the critical period studies conducted on different cultivated plants in Turkey (Uremis et al., 2009a; Tursun et al., 2015; 2016a, b; Isik et al., 2015; Isik and Akca, 2018; Karnas et al., 2019). Weeds found in the study area are generally highly competitive and considered to be a major problem (Holm et al., 1977). There were statistically significant differences in weed density in per squaremeter between 2018 and 2019 (Figure 1), which was 28.96 and 13.25, respectively. The densest species was *C. rotundus* with 14.28 m² in 2018 and *P. farcta* with 4.58 m² in 2019. In both years, densities of weeds were increased regarding to increasing duration of weediness (Figure 1). The dry weight increased as the weedy duration was increased in both years (Table 4). The total weed dry matter went up as the duration of weed interference period increased. Weed dry weight in 2019 was higher than in 2018. During the growing season, dry weights of weedy applications were determined as 17.80 g in 2018 and 185.00 g in 2019. Among the applications, the highest effect was determined in 90 days of weed-free application both years.

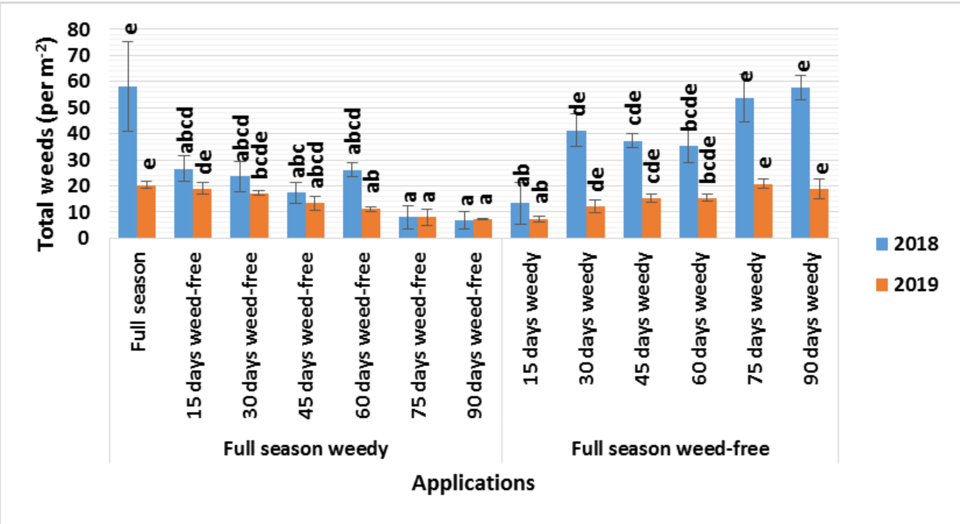

Figure 1. Changes in weed density in 2018 and 2019
Şekil 1. 2018 ve 2019 yıllarında yabancı ot yoğunluğundaki değişimler.

Table 4. Dry weight (g m-1) and impact rates applications (%) of the weed species found in the experimental area (2018 and 2019).
Çizelge 4. Deneme alanında (2018 ve 2019) bulunan yabancı ot türlerinin kuru ağırlığı (g m-1) ve uygulamaların etki oranları (%).

Treatments	2018		2019	
	Dry weight (g/m²) (+SE)	(%)	Dry weight (g/m²) (+SE)	(%)
Full season weedy	17.80 bc (+5.60)	0.00	185.00 c (+73.65)	0.00
15 days weed-free	4.65 abc (+3.26)	73.88	57.91 a (+4.91)	68.70
30 days weed-free	7.09 abc (+3.23)	60.17	49.25 a (+5.12)	73.38
45 days weed-free	1.96 ab (+1.48)	88.99	50.80 a (+3.15)	72.54
60 days weed-free	0.71 a (+0.19)	96.01	40.83 a (+0.54)	77.93
75 days weed-free	0.61 a (+0.46)	96.57	31.16 a (+2.12)	83.16
90 days weed-free	0.27 a (+0.25)	98.48	20.65 a (+0.39)	88.84
15 days weedy	1.27 a (+0.59)	92.87	45.83 a (+6.00)	75.23
30 days weedy	5.29 abc (+1.43)	70.28	86.67 ab (+34.92)	53.15
45 days weedy	6.25 abc (+4.06)	64.89	83.33 ab (+8.81)	54.96
60 days weedy	4.42 abc (+1.54)	75.17	95.00 ab (+8.77)	48.65
75 days weedy	20.48 abc (+13.25)	-	165.00 bc (+40.92)	10.81
90 days weedy	15.91 c (+7.13)	10.62	153.33bc (+10.92)	17.12

Differences between the applications were determined in terms of weed density and species richness between 2018 and 2019 (Table 5). The highest H diversity index value was in the weedy treatment for 15 days in 2018, which is 1,73 and weedy for 30 days in 2019, which is 1.74. The reason for this is that at the beginning of the competition, weeds and cultivated plant are together and compete with the sunflower. Diversity has decreased due to the growth of sunflower and the competition of weeds with each other in subsequent weed removal. Especially after the 60th day of weed removal, the increase in the rate of diversity emerges from weeds emerging in the later stages, i.e. the newly emerged and heat-loving vegetation. In the following periods, weeds, which were taller that can suppress other weeds, have increased their diversity rates to a certain extent with sunflower. The high diversity ratio (H) in weedy control is due to the surviving weeds. Although the high diversity value decreases the dominance value, the close number of weed species in the plot shows that there is no dominance in the environment. The fact that the diversity value was low (1.16) in the weedy plot for 30 days caused the dominance value to be high. The high dominance value was caused by the suppression of the *C. rotundus* species in the weedy plot for 30 days, suppressing other weed species. *C. rotundus* emerged as the most dominant species at all weed removal dates in 2018. *Chenopodium* species followed this weed. In 2019, the increase in the rate of diversity, especially after the 60th day of weed removal, was weeds emerging in the later stages of the newly emerged and heat-loving vegetation. The high dominance value in 2019 was due to the *C. rotundus* weed species, especially *P. farcta* suppressed other species (Table 5). The high dominance value in 2019 was due to the suppression of *C. rotundus* weed species, especially *P. farcta*, other species. In the studies conducted in 2018 and 2019, the diversity index (H) increased in the first 30 days. The reason for this is that the first development period of sunflower was slow and as a result, more variety of weeds emerge, and competition becomes higher. Similar to our study, Deligios et al. (2019) reported that the dominance of weed species may change depending on the growing season, climate data, and soil characteristics.

In the later weed removal, the diversity rate decreased due to the growth of sunflower and the competition of weeds among themselves. The weeds that emerged later, which were tall and were very competitive in suppressing other weed species, increased their diversity ratios somewhat, together with sunflower.

Table 5. The diversity index (H) of the weeds detected in the experimental area according to the applications and the dominance (Sd) of the important weeds

Çizelge 5. Deneme alanında tespit edilen yabancı otların uygulamalara göre çeşitlilik indeksi (H) ve önemli yabancı otların baskınlığı (Sd).

				Weeds (Sd)							
Years	Treatments	H	Sd	*C. album*	*C. vulvaria*	*C. tinctoria*	*C. arvensis*	*C. rotundus*	*F. officinalis*	*H. europeum*	*R. obtusifolius*
2018	15 days weed-free	1.73	0.19	0.069	0.009	--	0.027	0.069	0.001	0.017	0.001
	30 days weed-free	1.16	0.46	0.014	0.005	--	0.005	0.430	--	0.002	0.001
	45 days weed-free	1.33	0.34	0.088	0.002	--	0.002	0.237	--	0.002	0.005
	60 days weed-free	1.21	0.40	0.015	0.010	--	0.015	0.359	--	0.002	--
	75 days weed-free	1.48	0.32	0.011	0.024	--	0.008	0.271	0.001	0.002	0.003
	90 days weed-free	1.55	0.31	0.021	0.011	0.001	0.007	0.265	--	0.003	0.002
	Full season weedy	1.55	0.29	0.011	0.039	0.002	0.008	0.231	--	0.001	

	Treatments	H	Sd	*C. album*	*C. tinctoria*	*C. arvensis*	*C. melo var. agrestis*	*C. rotundus*	*H.europaeum*	*Physalis angulata*	*Prosopis farcta*
2019	15 days weed-free	1.68	0.20	0.022	0.001	--	0.006	0.082	0.006	--	0.082
	30 days weed-free	1.74	0.21	0.008	0.021	--	0.001	0.080	0.002	--	0.096
	45 days weed-free	1.47	0.30	0.005	0.001	0.004	--	0.210	0.001	--	0.079
	60 days weed-free	1.40	0.30	0.011	--	--	--	0.118	0.007	--	0.159
	75 days weed-free	1.45	0.31	0.006	0.001	--	0.001	0.072	0.005	0.001	0.221
	90 days weed-free	1.51	0.26	0.021	0.004	--	--	0.111	0.002	--	0.123
	Full season weedy	1.64	0.23	0.005	0.009	--	0.003	0.090	0.011	--	0.111

The variation ratio (H) in the control is due to the surviving weeds. Although the high diversity value decreases the dominance value, the close number of weed species in the parcel showed that there was no dominance in the environment. In 2018, *C. rotundus* emerged as the most dominant species at all weed removal times. *Chenopodium* species (*C. album and C. vulvaria*) followed this weed. The reason for the high diversity index value of the H diversity index value in weedy control on the 30th day is that, as in 2018, especially at the beginning of the competition, it is due to the competition between cultivated plants and weeds in sunflower in 2019. In 2019, as in 2018, the increase in the rate of diversity, especially after the 60th day of weed removal was due to weeds emerging in the later stages of the newly emerged and heat-loving vegetation (Table 5).

Based on the study, agricultural management and practices will be able to provide an advantage to the diversity of rapidly growing weed species. Marshall et al. (2003) stated that weed diversity can play a role in ensuring the sustainability of production systems. However, the high species and number of weeds in weed control reduces the crop yield and increases the CPWC at the same time (Table 3 and Table 6).

Table 6. The critical period of weed control (CPWC) for sunflower in 2018 and 2019 expressed in growing degree days (GDD) and days after crop emergence (DAE).

Çizelge 6. 2018 ve 2019'da ayçiçeği için yabancı otlarla mücadelede kritik periyot (CPWC) dönemi, toplam günlük gelişme derecesi (GDD) ve kültür bitkisi çıkışından sonraki günler (DAE).

Years	Yield reduction (%)	CPWC	
		GDD	DAE
The beginning of the CPWC			
2018	2.5	172	17
	5	243	24
	10	348	32
2019	2.5	201	13
	5	269	16
	10	364	21
The end of the CPWC			
2018	2.5	1416	98
	5	1181	86
	10	978	74
2019	2.5	1734	87
	5	1409	72
	10	1136	59

Critical period for weed control

There was an interaction between years and the treatments; therefore, data were assessed separately each year (Figure 2, Table 7). Sunflower yield varied with the duration of weed remove times or weed-free periods (Figure 2). The relative yield of sunflower was altered by the duration of weed interference or weed free periods. As the weed periods got longer, significant reductions in sunflower yield were determined in both years. In 2018 and 2019 during the growing season, the sunflower yield was determined as the highest (3220.4 kg ha^{-1}, 4206.1 kg ha^{-1}, resp.) in season-long weed-free plots, and the lowest (1898.7 kg ha^{-1}, 2618.9 kg ha^{-1}, resp.) in season-long weedy plots. Due to weeds, 41.04 % yield loss in 2018 and 37.74 % in 2019 were occurred. The longer the weedy duration, the lower the yield and the increased dry weight. In both years, it has been determined that as the GDD increases, the yield increases in the weed-free and the yield decreases rapidly in the weedy plots. In other studies, on sunflower, yield loss results reported as 25.7% (Wanjari et al. 2000), 27.5-43% (Hossein et al. 2010), 39% (Serafin et al. 2014) and 51.87% (Mukhtar et al. 2018), highly similar to our work. The reason for the high yield in 2019 may be the change in planting time due to changes in climate factors and changes in weed density.

In 2018 and 2019, the CPWC in sunflower was calculated and the acceptable yield losses (AYL) for 10%, 5%, and 2.5% were determined (Figure 2, Table 6). The CPWC varied in both years (Figure 2).In 2018 CPWC 172-1414 GDD (Growing degree days) for 2.5 % AYL, 243-1181 GDD for 5 % AYL, and 348-978 GDD for 10 % AYL (Table 6). For 5% AYL, these GDD corresponds 24th to 86th days after sunflower emergence. In 2019, the CPWC in sunflower was calculated as 269 GDD at the beginning of the critical period for weeds in sunflower at 5% AYL, which corresponds the 16th day after sunflower emergence (Table 6). The end time of the CPWC for sunflower at 5% AYL was calculated as 1409 GDD corresponding the 72nd day after the sunflower emergence (Table 6). The differences in CPWC in years might be attributed to the difference dates for planting and harvest. In addition, the changes between the critical periods in both years was due to the differences between the weed species and their density, as indicated in Table 3, as a result of the different precipitation amounts (Tursun et al., 2007).

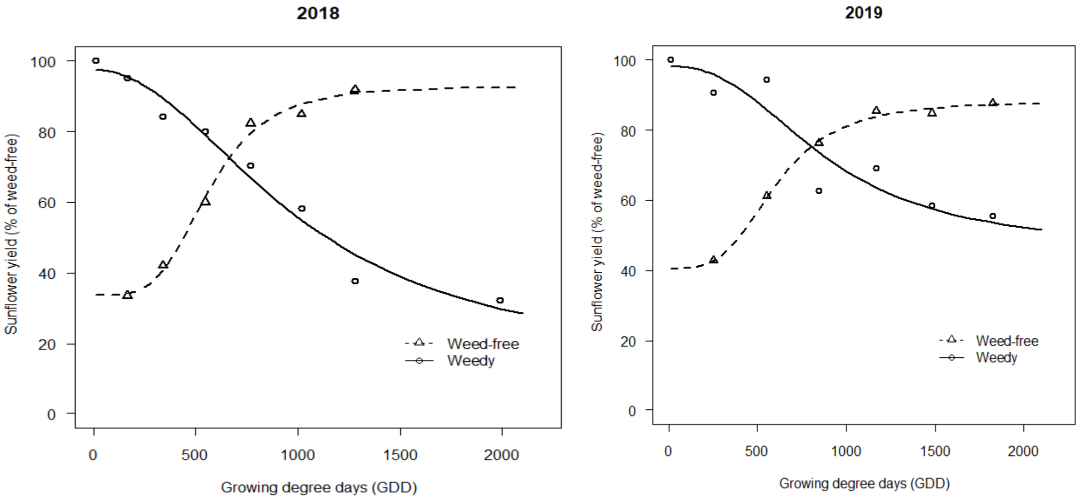

Figure 2. Effect of weed interference on sunflower yield (% of weed-free) as represented by growing degree days (GDD) in 2018 and 2019. The regression lines are plotted using Equation 2, and the parameter values are presented in Table 7.

Şekil 2. Yabancı ot alım zamanlarının 2018 ve 2019'da günlük gelişme derecesi toplamı (GDD) ile temsil edilen ayçiçeği verimi (% yabancı otsuz) üzerindeki etkisi. Regresyon çizgileri Denklem 2 kullanılarak çizilmiştir ve parameter değerleri Tablo 7'de sunulmuştur.

Table 7. Parameters (± SE) determined for the four-parameter log-logistic model applied for the weedy and weed-free period in the proportional yield of 2018-2019 sunflower.

Çizelge 7. 2018-2019 yıllarında ayçiçeği oransal veriminde yabancıotlu ve yabancıotsuz dönem için uygulanan dört parametreli log-lojistik model için belirlenen parametre (± SE) değerleri.

		Regression parameters (±SE)			
	Treatments	*B*	*C*	*D*	I_{50}
2018	Weedy	2.08 (0.6)	13.7 (14.7)	97.4 (3.2)	1002.5 (179.6)
	Weed-free	−3.96 (1.3)	33.7 (3.8)	92.9 (4.7)	561.9 (38.4)
2019	Weedy	2.47 (2.6)	46.1 (24.4)	98.1 (5.5)	886.4 (398.3)
	Weedy	−3.46 (0.9)	40.6 (3.2)	88.2 (2.2)	602.3 (37.7)

B: the slope of the line at the inflection point; C: the lower limit; D: the upper limit; I_{50}: the growing degree days giving a 50% response between the upper and the lower limit.

B: doğrunun eğim noktası; C: alt sınır; D: üst sınır; I_{50}: üst ve alt sınır arasında %50 yanıt veren günlük büyüme dereceleri.

A period of 1-1.5 months was reported as the critical period in the study conducted in Tokat/Turkey (Iyigun et al. 1997) and although pre-emergence herbicide was recommended, it was calculated that this may not be necessary in the current study. It is estimated that weeds can be kept under control only with the application of herbicides post-emergence, together with the mechanical controls to be performed on sunflower, which is an anchor plant. The difference between the studies is thought to be due to the fact that the studies were conducted in very different ecologies such as Erzurum, Tokat and Adana in Turkey (Zengin, 1999; Iyigun et al., 1997). Gholipour et al., (2010), Asghari et al., (2011), Silva et al., (2012), Knezevic et al., (2013) and Yalcin et al., (2020) determined that the critical period is between 7- 68, 10-79, 15-39, 14-26 days and 2-10 weeks, respectively. Among other investigators, Wanjari et al., (2000) 25-43, Serafin et al., (2014) 1-49 and Mukhtar et al., (2018) 14-56 determined that there is critical period between days. The main reason why these results differ from our study is the ecological differences in the places where the studies were carried out, as well as the weed species and populations. Furthermore, several studies have shown that the outcome of CPWC was variable and highly dependent on weed population density, competitiveness, and period of emergence. In addition, some studies have shown that CPWC was change depending on population density, competitiveness and emergence times of weeds (Evans et al., 2003; Bukun, 2004).

Amador-Ramirez (2002) stated that knowing the behavior of weeds in crop plants was important for a better understanding and development of an Integrated Weed Management System (IWM). The use of pre-emergence herbicides can control early emerging weeds and delay the beginning of the critical period. In this study, it can be a practical option for designing an effective IWM strategy for weed control in sunflower. With a better understanding of CPWC in sunflower production, it may be possible to avoid unnecessary and costly weed control measures, to rely less on the use of permanent soil residue herbicides, and to use post-emergence herbicides more consciously (Knezevic et al., 2002).

CONCLUSIONS

Weed flora is considered to be one of the main reasons interfering with the quantity and quality of agricultural production. As a result of the study, the most important weeds were *Cyperus rotundus* and *Prosopis farcta*, respectively in 2018 and 2019. CPWC was determined to be between 2^{nd}-3^{rd} and 10^{th}-12^{th} weeks to achieve an acceptable 5% yield loss. In order to develop an effective weed management in sunflower, control of weeds in the critical period is an important factor and our study results may contribute significantly to weed control for Turkish sunflower growers.

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Author's Contributions

The contribution of the authors is equal.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

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